

HYDRAULIC ELECTRONIC UNIT INJECTOR (HEUI) TESTING BENCH

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ABSTRACT

This paper presents a suggested injector test bench construction, and also testing of its performance and application, because there is no device for testing the workability for this kind of injectors. Also, service dealers in Jordan and Middle East replace all injectors of any equipment, equipped with this kind of injectors when an overhaul for the engine is needed, which means at least eight injectors are replaced even if not all of them are not working properly. So, this bench will save a lot of money if the properly working injectors are not replaced; knowing that each single injector costs around \$1900. When testing the injector, it could be known from the problem existed after analysis, the type of maintenance needed for this injector.

KEYWORDS: Hydraulic Test Unit, Injector & Internal Combustion Engines

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1. INTRODUCTION

The constructed bench will be used to make tests on the injectors of the 3408E/3412E CATERPILLAR (CAT) engines equipped with the HEUI fuel system, which are available in construction equipment and industrial applications. Industrial engines are available in both 3408C/3412C (pump and line fuel system) and 3408E/3412E HEUI versions. CAT machines powered by the 3408E/3412E engines which feature HEUI include: 769/771/773/775 Off -highway Trucks, 988F/990 Series II Wheel Loaders, D9R/D10R Track-type Tractors, 631E/637E/651E/657E Wheel Tractor-Scrapers, 24H Motor Grader, 5110B Excavator.

The HEUI engines have many features and benefits, not possible with mechanical fuel systems. These features include a very clean exhaust, improved fuel consumption and cold starting, simplified maintenance with fewer moving parts, and reduced operating costs. Figure 1 shows the HEUI injector with section view. [1]



Figure 1: HEUI Injector with Section View

2. HEUI TESTING BENCH

The HEUI testing bench shown in Figure 2 is a mechanical actuated, electronically controlled device, used to check the workability of HEUI injectors by checking the amount of injected fuel and visual inspection of the spray pattern. This testing method by using this device will tell us, if the injector is working properly or not. It could also give an indication to what part of injector is defective according to the injector behavior during the test, so this could lead to the exact analysis of the problem and solution without the need to replace the injector. Maybe replacing some part of the injector will be enough, so this device could help to find a way to provide maintenance for this kind of injectors rather than testing. But, at least there will be no need for replacing an expensive injector that is working properly for no good reason [2].

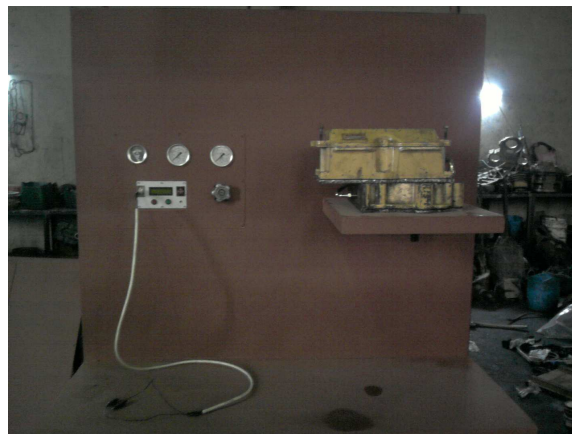


Figure 2: HEUI Testing Bench

This device includes the following parts: Hydraulic oil pump and tank, Fuel pump and tank, Measuring tools (oil pressure gauge, oil temperature gauge, fuel pressure gauge), and Control unit.

Some of test bench advantages: it is capable to check the injector's workability, no need to replace proper working injectors, which save a lot of money; it is capable to check the injector at different hydraulic oil pressure, programmable controller which controls the injector operating, and easy to replace the injectors on the test bench [1].

3. TEST BENCH DISADVANTAGES

It cannot test the injector at the exact conditions, as it's on the engine (working temperature, pressure variations and number of injections). It can only test one injector at a time. The Hydraulic Supply Pump Group ((2) Figure 3) is mounted in the V of the engine in the same position as the original fuel pump and governor for the 3408C/3412C engines. Flow from this pump supplies the actuating pressure for the injectors. Mounted on the rear of the pump is the fuel transfer pump [1, 2]

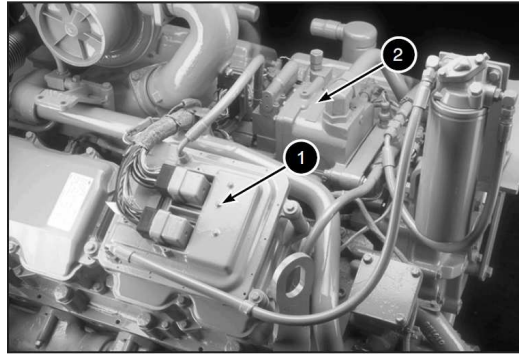


Figure 3: Principal Component in the HEUI System

4. INJECTOR COMPONENTS

The HEUI injector was designed with a minimum of component parts. The injector contains 35 part numbers. This exploded view (Figure 4) shows all the components by assemblies as follows: The Valve Body Group contains the solenoid, armature and the poppet valve. This assembly directs the oil to the hydraulic intensifier piston, which moves the fuel plunger. The Barrel Group contains the high pressure fuel plunger. The Nozzle Group contains the case, tip, check valve and nozzle. [1]

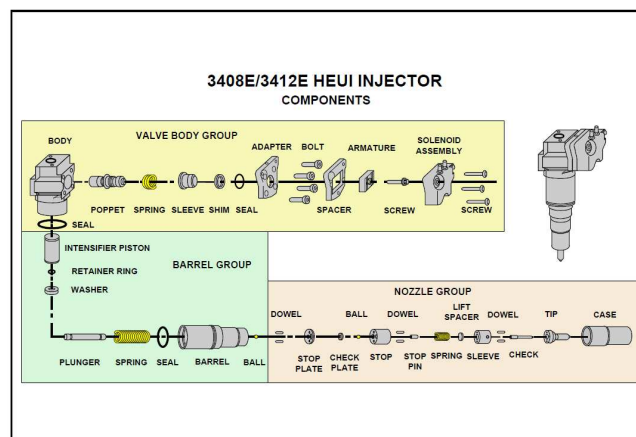


Figure 4: HEUI Injector Components

5. INJECTOR COMPONENT PARTS

As shown in Figure 5, the component parts in the three basic groups were discussed previously. The valve body has three parts (body, adapter and spacer), which are assembled with great precision.

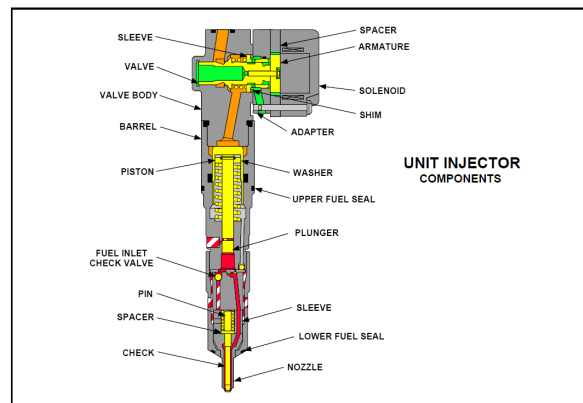


Figure 5: Component Parts

Matthew K. et al. (2015) investigated JP-8 sprays from a hydraulically actuated and electronically controlled unit injector (HEUI), and a common rail injector (CRIN) to compare the effects of the fuel delivery system on the spray behavior of the fuel. The fuel pressurization method between injectors is fundamentally different. During the ROI experiments with the HEUI, the oil temperature and pressure was varied from 45°C to 90°C and 142-200 bar, respectively. Results showed that an increase in oil temperature for the HEUI will increase the injected fuel mass. The CRIN injector system showed 4 times more precise control of injected fuel mass compared to the HEUI, and the CRIN showed less variations in the hydraulic delay. Comparing the plume to plume transient spray, behavior of the two systems showed that more variations were present with the HEUI injector. However, the overall transient liquid penetration behavior was similar for both injection systems. Results of this study can be used to optimize the design of engines using JP-8 with hydraulic fuel injectors, thus improving fuel efficiency and power output.

Hsun-H. and Chyuan-Y. (2010), focuses on developing a sensor identification algorithm that can clearly classify the usability of the solenoid valve, without disassembling the fuel pump of an EDC system for in-use agricultural vehicles. A diagnostic algorithm is proposed, including a feedback controller, a parameter identifier, a linear variable differential transformer (LVDT) sensor, and a neural network classifier. Experimental results show that the proposed algorithm can accurately identify the usability of solenoid valves.

6. EXPERIMENTAL WORK

This part of the documentation discusses the whole test bench system design, which could be branched into two parts of design and job: Mechanical design and Electrical design.

Note: since that the calculations and mechanical couplings between mechanical parts from the first stage of this under graduation project were redesigned, based on actual values and readings (amount of injected fuel), the mechanical design will be discussed firstly.

6.1 Mechanical Design

This branch includes the following parts: Pumps selection. Fuel Filter, Fuel & oil lines, Oil pressure regulator, Pressure gauges, Temperature gauge, Fuel & oil tanks and Test bench design.

6.2 Pump Selection

First of all, for electrical motor selection, it was needed to know the volume of hydraulic oil that should be

supplied to the injector per injection to calculate the horse power that should be supplied to the pump from the electrical motor. So, the hydraulic oil chamber in the injector was measured after disassembly. Then, these results were concluded: Hydraulic oil chamber diameter (cylindrical shape) = 2.1 cm Hydraulic oil chamber height = 1 cm

$$volume = \pi r^2 h = \pi (1.05)^2 (1) = 3.464 \text{ cm}^3$$

The operating pressure for the injector is set at 3000 psi as a maximum pressure of the hydraulic oil pump. Then, the flow (Q) will equal the pressure multiplied by the volume. Here it was supposed that, the injector will operate at 50 injections per minute.

$$Q = (50 \text{ inj./min.}) \times (3.464 \text{ inj.}) = 173.2 \text{ cm}^3/\text{min} = 0.1732 \text{ lit/ min} = 0.046 \text{ gpm}$$

Multiplying the above calculations by a safety factor of 4 and we got:

$$Q = 0.1732 \text{ lit/ min} \times 4 = 0.7 \text{ lit/ min} = 0.2 \text{ gpm}$$

Because of the bounded ranges available in markets, we found that the best available pump is 1 lit/min and a maximum pressure of 3000 psi (pump type TUROLLA PLESSEY TF-102).

1 lit/min = 0.264 gpm. For this pump, the electrical motor was selected by the following calculations:

$$electrical \text{ motor } HP = \frac{(gpm)(psi)}{1714} = \frac{(0.264)(3000)}{1714} = 0.462 \text{ HP}$$

Multiplying the above calculations by a safety factor of 4 and we got: ^[2]

$$HP = 0.462 \times 4 = 1.85 \text{ HP}$$

Because of the bounded ranges available in markets, it was found that the best available electrical motor is 2 HP (electrical motor type ARNOLD MULLER 220V AC (Figure 6)) [2, 3].

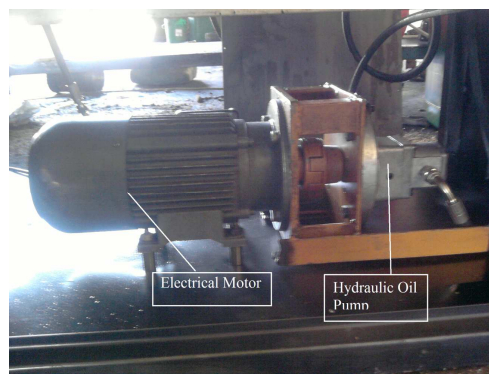


Figure 6: Hydraulic Oil Pump & the Electrical Motor [3]

6.3 Test Bench

Holder and keeper for all mentioned parts (Figure 7).



Figure 7: Test Bench

Hardware (control circuit & electrical sources circuits) are shown in (Figure 8) and (Figure 9):



Figure 8: Controller

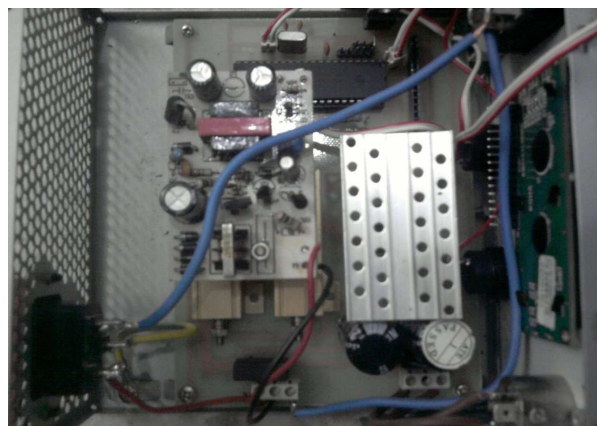


Figure 9: Controller Components

6.4 Software (Programming Flow Chart)

The flow chart (Figure 10) explains the programming of the PIC microcontroller. When the process starts (Start), it will face a condition (Is Button pressed); if no the process returns to the condition again and again (infinite loop). If yes, a counter loop starts from 49 (Counter C = 49), after that port 33 of the PIC Microcontroller will pulse the injector solenoid on (Port 33=1) for three millisecond (Wait 3 ms, then off (Port 33=0) for one second (Wait 1 s) and every time the counter

will be decreased one step (Dec C). Then, the process faces another condition (Is C = 0); if no the process returns to complete the pulses of the counter (Port 33 = 1). [4, 5]

If yes, the process ends (END).

By the completion of this program, the injector solenoid will be pulsed on and off, for fifty times, which means that the injector will inject fifty injections to complete the test in approximately one minute.

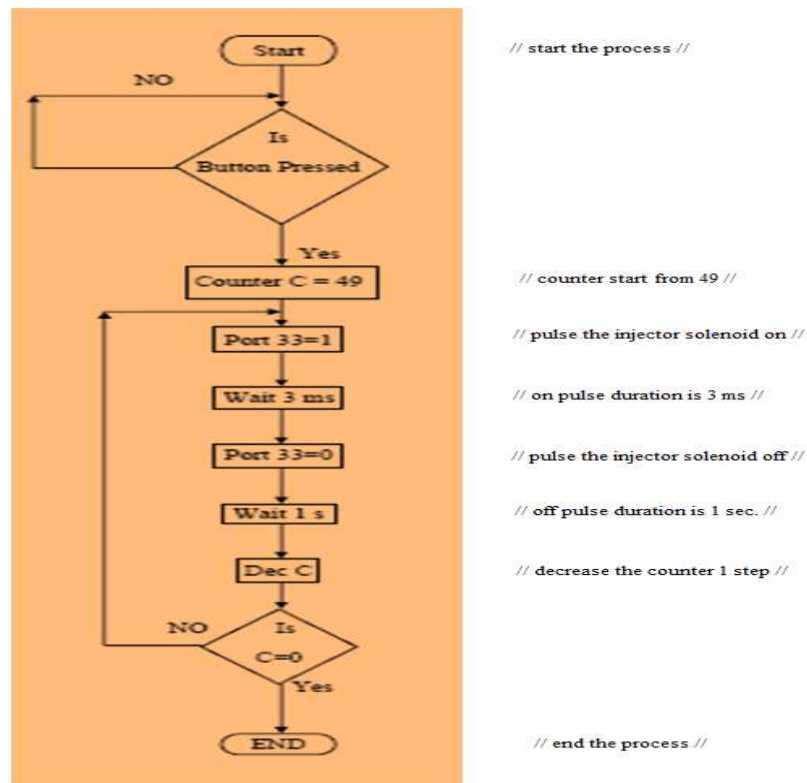


Figure 10: Flow Chart [5]

7. RESULTS AND DISCUSSIONS

From the tests applied on nine injectors, the average quantity of fuel injected depending on various pressure values and fixed electrical signal duration at three millisecond. Every single test takes approximately one minute, during this time fifty injections are applied on the injector. So, in the next section of data and results, the quantity measurements will indicate the amount of injected fuel in fifty injections and the various pressure values will indicate the hydraulic oil pressure. The various pressure values are determined to approximately simulate the conditions applied on the engine. Figure 11 show Pressure vs. Quantity variations for injector number 1. From these results, it's shown that (700 psi) is not enough to displace the plunger, so there is no fuel injected. From 800 – 2000 psi introduced ample pressure to displace the plunger and inject in different quantities of fuel proportional to pressure values. For more than 2000 psi fuel, quantity is constant because the plunger moves its full stroke.

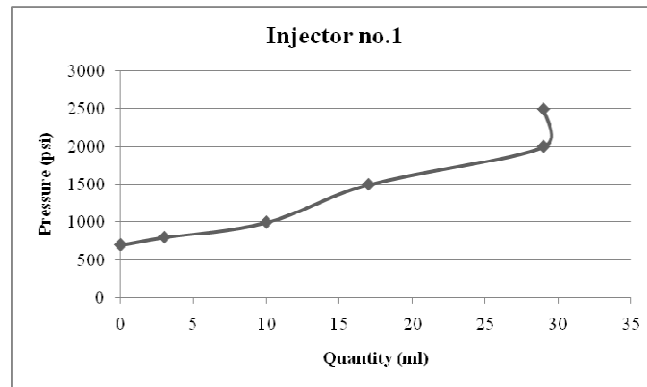


Figure 11: Injector No. 1

Figure 12 shows Pressure vs. Quantity variations for injector number 2. From these results, it's shown that 700 psi is not enough to displace the plunger, so there is no fuel injected. From 800 – 2000 psi introduced ample pressure to displace the plunger and inject different quantities of fuel proportional to pressure values. For more than 2000 psi, fuel quantity is constant because the plunger moves its full stroke.

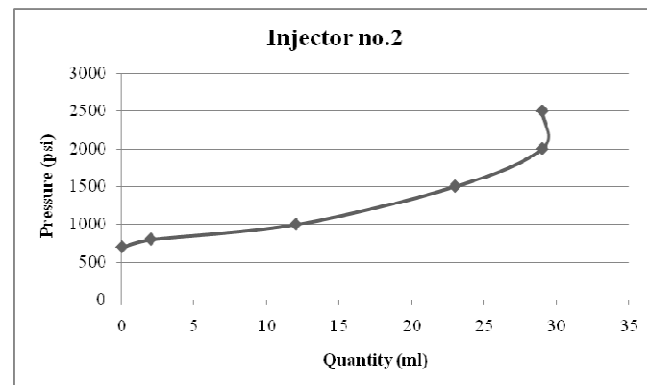


Figure 12: Injector No. 2

Figure 13 shows Pressure vs. Quantity variations for injector number 3. From these results, it's shown that 700 psi is not enough to displace the plunger, so there is no fuel injected. From 800 – 2000 psi introduced ample pressure to displace the plunger and inject different quantities of fuel, proportional to pressure values. For more than 2000 psi, fuel quantity is constant because the plunger moves its full stroke.

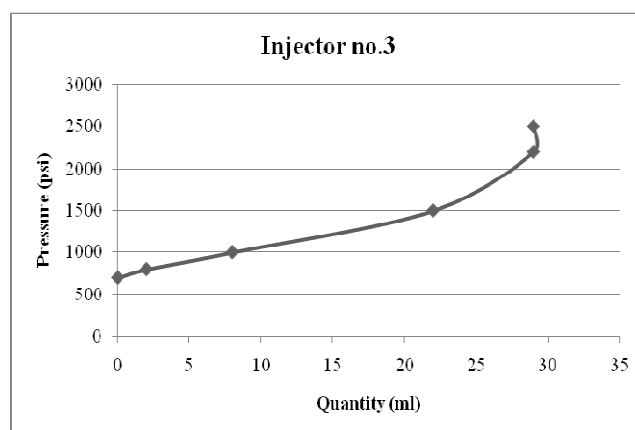


Figure 13: Injector No. 3

Figure 14 shows Pressure vs. Quantity variations for injector number 4. From these results, it's shown that 700 psi is not enough to displace the plunger, so there is no fuel injected. From 800 – 2000 psi introduced ample pressure to displace the plunger and inject different quantities of fuel, proportional to pressure values. For more than 2000 psi, fuel quantity is constant because the plunger moves its full stroke.

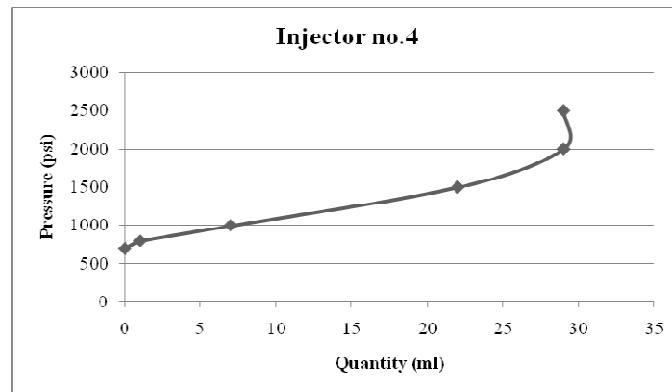


Figure 14. Injector No. 4

Figure 15 shows Pressure vs. Quantity variations for injector number 5. From these results, it's shown that 700 psi is not enough to displace the plunger, so there is no fuel injected. From 800 – 2000 psi introduced ample pressure to displace the plunger and inject different quantities of fuel, proportional to pressure values. For more than 2000 psi, fuel quantity is constant because the plunger moves its full stroke.

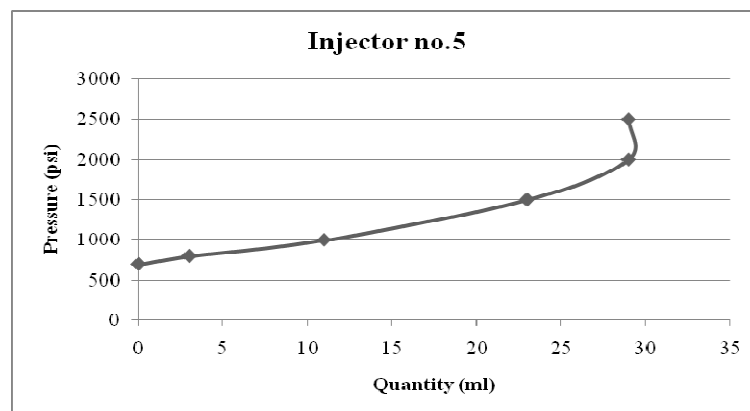


Figure 15: Injector No. 5

Figure 16 shows Pressure vs. Quantity variations for injector number 6. From these results, it's shown that 700 psi is not enough to displace the plunger, so there is no fuel injected. From 800 – 2000 psi introduced ample pressure to displace the plunger and inject of different quantities of fuel, proportional to pressure values. For more than 2000 psi, fuel quantity is constant because the plunger moves its full stroke.

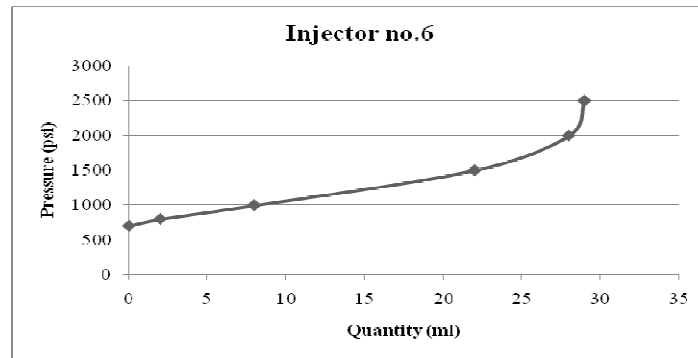


Figure 16: Injector No. 6

Figure 17 shows Pressure vs. Quantity variations for injector number 7. From these results, it's shown that 700 psi is not enough to displace the plunger, so there is no fuel injected. From 800 – 2000 psi, introduced ample pressure to displace the plunger and inject of different quantities of fuel, proportional to pressure values. For more than 2000 psi, fuel quantity is constant because the plunger moves its full stroke.

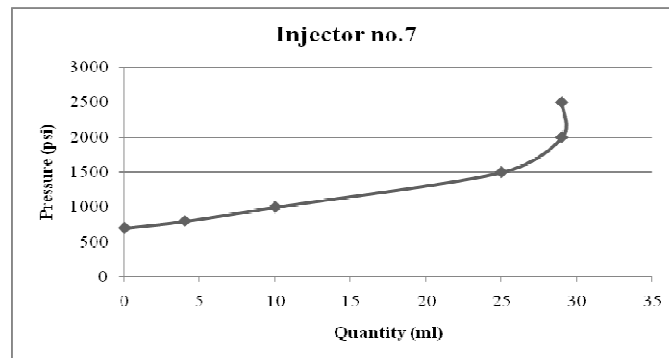


Figure 17: Injector No. 7

Figure 18 shows Pressure vs. Quantity variations for injector number 8. From these results, it's shown that from 700-800 psi, it is not enough to displace the plunger, so there is no fuel injected. From 1000-2500 psi, introduced ample pressure to displace the plunger and inject of different quantities of fuel, proportional to pressure values.

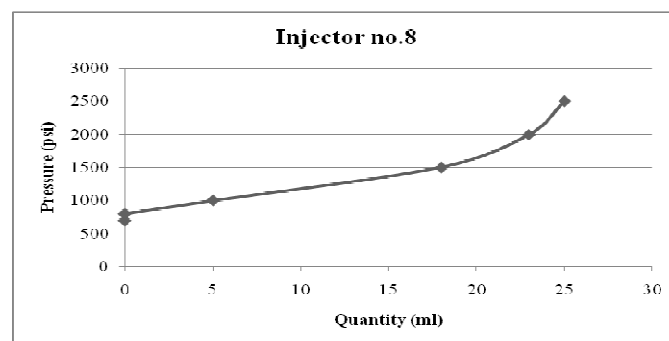


Figure 18: Injector No. 8

Figure 19 shows Pressure vs. Quantity variations for injector number 9. From these results, it's shown that from 700 – 2500 psi, there is no fuel injected.

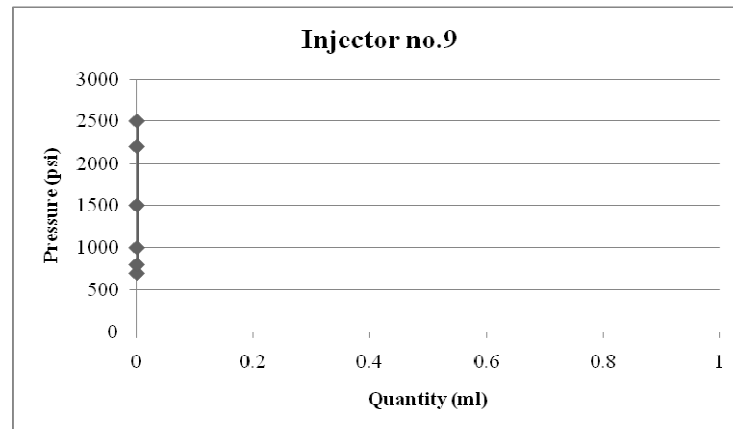


Figure 19: Injector No. 9

Discussions

The studied injectors were removed from properly working equipment and tested to make the reference average for the injectors, which will be tested on the HEUI Testing Bench. As shown in Figure 20, the injector does not operate below (800 psi), and this was proved when no one of the injectors injected any fuel (0 ml) at 700 psi. At 800 psi, the amount of injected fuel was between (1-3 ml), which is approximately the minimum amount of the injected fuel, because (800 psi) displace the plunger for a short displacement from the full stroke. Then, when increasing the pressure (1000-1500 psi), the displacement of the plunger increased, as a result, the amount of injected fuel increased. For the values of pressure (2000-2500 psi), the quantity of injected fuel was constant, which indicates that theses values of pressure are enough to displace the plunger its full stroke.

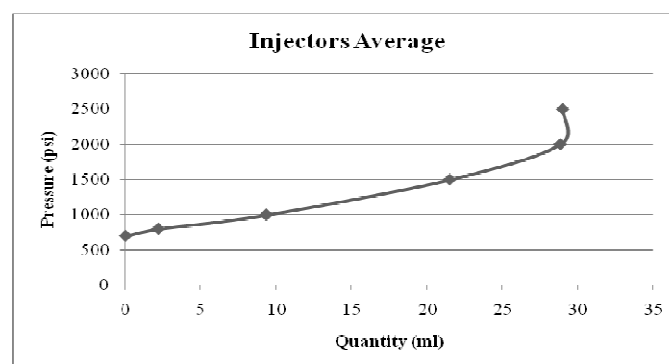


Figure 20: Injectors Average

The cloudy characteristic of the spray pattern differs from low pressure to high pressure; when the pressure increases, the spray pattern cloudy shape increases (Figure 21).



Figure 21: Cloudy Spray Pattern

These injectors were tested on the HEUI Testing Bench, and obviously they are defected. It was obvious from visual inspection that there is fuel leakage from the nozzle check valve, and the spray pattern cloudy shape wasn't introduced (large fuel drops). *For Injector number 7:* We noticed from the results of this injector that fuel quantities (from 800 – 1500 psi) increased from reference injectors' average. Fuel quantity from 2000 – 2500 psi were equal to the reference average, but the cloudy shape of the spray pattern wasn't introduced (large fuel drops).

For injector number 8: It was obvious from visual inspection that, there is a pressure leakage due to oil drain leakage, and the spray pattern cloudy shape was smaller than the expected at the different pressure values. As we noticed from the results of this injector, the fuel quantities decreased from the reference injector average.

For injector number 9: For this injector, it was obvious from visual inspection that the solenoid was defected, because it wasn't able to move the poppet at any pressure value. As we noticed from the results of this injector, there was no injected fuel at any pressure value.

8. CONCLUSIONS

A well knowledge of HEUI system was experienced in field. This test is useful for the people, who use the CAT equipments which are equipped with HEUI system. The benefit of this project is that, it saves a lot of money by testing the injectors with visual inspection to the whole process, to identify the properly working injectors from the improperly working ones, which is not available at any of CAT service centers or any injector's workshops in Jordan. Also, CAT dealer in Jordan replaces all the injectors of any engine equipped with this kind of injectors when an overhaul for the engine is needed. It means, eight or twelve injectors will be replaced, even if not all of them need to be changed.

This test bench will test and check if the injectors need to be replaced or not, knowing that each injector costs 1300 JD. On the equipment the amount of fuel injected depends on these variable factors: Hydraulic Oil Pressure, Electrical Signal Duration. Also in this test bench, the duration is set to three millisecond (constant duration) and variance pressure. By doing this, the amount of fuel injected differs according to pressure values variations. Then, an average for the proper working injectors has been made, including variations of the amount of injected fuel at different pressure values, which could be used later to compare it to other tested injectors.

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